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RHIC POWER SUPPLIES-FAILURE STATISTICS FOR RUNS 4, 5 AND 6*

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Abstract

The two rings in the Relativistic Heavy Ion Collider (RHIC) require a total of 933 power supplies to supply current to highly inductive superconducting magnets. Failure statistics for the RHIC power supplies will be presented for the last three RHIC runs. The failures of the power supplies will be analyzed. The statistics associated with the power supply failures will be presented. Comparisons of the failure statistics for the last three RHIC runs will be shown. Improvements that have increased power supply availability will be discussed. Further improvements to increase the availability of the power supplies will also be discussed.

INTRODUCTION

This paper was written to present the following reliability statistics for runs 4, 5 and 6:

- Average Failure Hours per week
- Mean Time Between Failure (MTBF) of everything the Collider Electrical Power Supply (CEPS) group is responsible for.
- % Availability of the RHIC machine if only the CEPS group failures (everything CEPS is responsible for) are considered.
- MTBF of only power supply (p.s.) failures.

These statistics are compared from run to run to evaluate the performance of the RHIC p.s.'s. These statistics can also be used to compare how the RHIC p.s.'s are performing compared to p.s.'s from other laboratories if they have MTBF statistics. Some of the major problems and improvements with the RHIC p.s.'s will also be discussed.

STATISTICS

Average Failure Hours/Week

The Average Failure hours per week are maintained by the Main Control Room [1]. These numbers are calculated independent of the CEPS group MTBF statistics and we use these numbers to confirm our numbers. These are the average failure hours for 4, 5 and 6.

Table 1: Average Failure Hours/Week

Run	Average Failure Hours/Week
Run 4	3.29
Run 5	2.4
Run 6	4

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MTBF of RHIC due to any ps failure

The MTBF of RHIC due to any ps failure is the average time, in hours, that RHIC can run before experiencing any failure associated with the CEPS group's responsibilities. This is not limited to only p.s. problems. For example this would even include Quench Protections Assemblies (QPA's), Node Cards, and Connections, to name a few.

Equation 1 is the formula used to calculate this MTBF.

$$MTBF_{ps_any} = \frac{MT}{NOF} \quad (1)$$

MT, in equation 1 stands for Machine Time. NOF is the number of failures. This is how MT is calculated by the CEPS group:

- MT is the time that only the RHIC p.s.'s are up and available for use by the RHIC physicists. If the RHIC p.s.'s are up, meaning no failures, then this adds to the MT.
- If there is a failure in anything the RHIC ps group is responsible for then the time gets subtracted from MT because the machine is not up AND the NOF (number of failures) increases as well.
- If RHIC is down for another failure, but the RHIC p.s.'s are still ready to go, then we still add this time to the MT. We do not subtract time from MT due to other group's failures. We still add time to the MT even if the machine is down for another failure because the RHIC p.s.'s are still available for use
- If the RHIC p.s.'s fail because of something our group is not responsible for then we do not subtract this time from the MT that the p.s.'s were down for. This is because the RHIC p.s.'s would have been available for use if something else did not cause them to fail. The NOF would NOT increase either because the failure was not our responsibility.
- Some common examples of other failures that DO NOT increase the RHIC ps group's NOF and DO NOT subtract time from MT are: beam induced quenches, power dips, Main Control Room operator errors, and cryo lead flow faults
- Scheduled and Non-scheduled maintenances are subtracted from MT because the p.s.'s are being worked on during this time and are not available for use. All groups are working on their equipment during maintenance days. Therefore, the RHIC p.s.'s are not available because there is maintenance time, there are no failures. So time is subtracted from MT. Table 2 lists the MTBF_any_ps for runs 4,5, and 6.

Table 2: MTBF_any_ps

Run	MTBF_any_ps (Hours)
Run 4	20.48
Run 5	30.79
Run 6	28.23

% Availability

% Availability (%AV) is the percentage of time RHIC would be available if you considered failures only due to the CEPS group. %AV is calculated using equation 2.

$$\%AV = \left[\frac{MT - (NOFxTOR)}{MT} \right] \times 100 \quad (2)$$

TOR is the average time of repair. Every time a CEPS group technician goes out on a repair he reports back with how long the repair took. We also have a 2 man rotating shift and if they make the repair we can estimate from the logs how long the repair took. If an engineer is called at home we also keep track of how long the engineer was on the phone working with the 2 technician's on shift. The average repair times for the past 3 runs are listed below:

- Run 4 TOR = 44 minutes
- Run 5 TOR = 54 minutes
- Run 6 TOR = 50 minutes

The NOFxTOR is the average downtime due to everything the CEPS group is responsible for. When (NOFxTOR) is subtracted from MT and divided by MT you come up with the percentage of time RHIC would have been available if you only considered failures of the CEPSSG. Table 3 lists the %AV for runs 4, 5, and 6.

Table 3: %AV

Run	%AV
Run 4	91.97
Run 5	97.09
Run 6	95.03

MTBF of power supplies only

MTBF_ps_only tells us the average number of hours we can run before experiencing a p.s. failure. This does not consider any other failures that the CEPS group is responsible for. It only considers p.s. problems. Equation 3 is how MTBF_ps_only is calculated:

$$MTBF_ps_only = \frac{(MT \times NOPS)}{NOF} \quad (3)$$

NOPS is the number of p.s.'s. There were a total of 933 p.s.'s in RHIC for Runs 4,5 and 6.

There are 5 categories of the RHIC p.s.'s

- Correctors, quantity = 620
- Insertion Region p.s.'s = 237
- Main p.s.'s, quantity = 4
- Gamma-T p.s.'s, quantity = 24
- Sextupole p.s.'s, quantity = 24, (run 7 total 48)
- Snake and Rotator p.s.'s, quantity = 24

Table 3 lists the MTBF_ps_only for runs 4,5 and 6.

Table 3: MTBF_ps_only

Run	MTBF_ps_only (Hours)
Run 4	19106
Run 5	27989
Run 6	26339

MAJOR PROBLEMS

Run 4

The corrector p.s.'s were swapped out 25 times in run 4. The dominant problem was unexplained error trips. During the run it was determined that the undervoltage circuit and failure on the dcct card were the reason for this. This was fixed during the shutdown after run 4.

The unipolar insertion region p.s.'s had a problem with error trips which was due to the ON status being lost after turn on. This was because the wrong type of relay contacts were being used. 19 of these relays had to be replaced during the run. This was also fixed during the summer shutdown after run 4. The total number of times the insertion ps's failed for run 4 was 24.

The main p.s.'s caused tripped 46 times during run 4. There were different errors during these trips but 3 were more dominant than others. There was a problem with a connector on the yellow dipole DCCT. This caused 8 trips before it was discovered and repaired. There were 7 trips on the yellow dipole p.s. due to a snubber capacitor that touched ground because double sided tape on zero gravity hold downs dried out over time. There were 5 trips due to a bad crimp on a wire of the PFN circuit. The other faults were regulator errors, oscillation, and current monitor faults.

There were also 20 trips related to a problem in one of the service buildings with an opto-isolator that was not being driven hard enough in the permit module and this would cause the quench link to drop unexpectedly. This was repaired during the shutdown after run 4.

One of the major problems in run 3 which was fixed in run 4 was ice forming on the base of the magnet trees in the tunnel. These trees are where the DC cables insert into a terminal block for the corrector and sextupole magnets. There are voltage tap boxes on these trees as well for the main ring magnets. The cryo lead flows also enter these trees and caused ice build up around the tree which would cause ground faults and other problems. Installing foam insulation around the trees, heaters under the foam with thermostats as well as one wire temperature sensing devices fixed this problem.

Run 5

The number of correctors replaced in run 5 improved to 10 from the 25 in run 4. The main ps trips improved to 5 compared with 46 in run 4.

The insertion region p.s.'s still had 51 trips. The dominant problems were quench protection assembly (QPA) fan switch faults (12 trips), current regulator card relay failures (6 trips), a loose gate drive connection in a p.s. which caused 9 trips in itself until the p.s. was swapped out, pre-molded D connector cables built on the outside accounted for 8 trips and connection problems with insulation displacement connectors (4 trips). During the shutdown after run 5 test points were added to measure the voltage across the qpa fan switch so we could predict when it was going bad. We could also jumper it out if need be before it caused a failure. There are overtemperature interlocks to still protect us. The bipolar 150A p.s.'s were swapped out 9 times in run 5. Five were not reproducible on the bench although work to possibly fix the fault was done to each p.s.

The quench detector system accounted for 19 trips as well. 14 trips were due to 3 hardware problems that were fixed (single gain mux card, fan fail and loose voltage tap wires). Two software problems caused 5 trips.

Run 6

In run 6 the corrector p.s.'s continued to improve and 6 were replaced vs. 10 in run 5. Run 6 started out quite well but we started having many problems the last 3 weeks of this run. The p.s.'s were asked to run at higher currents these last 3 weeks for high energy polarized proton operation, and the weather started to get hot and humid. All of the RHIC ps's are air cooled and there is no air conditioning in the part of the building that these p.s.'s reside in, as of run 6.

The 2 major problems we had at this point were trips on the main p.s.'s and running the bipolar 300A p.s.'s at high current. The main p.s. problems were mostly linked to the PFN circuits (5 trips). One of the PFN circuits appeared to be discharging for no reason causing a PFN fault. This happened when it was very humid out. During the shutdown after run 6 all of the PFN high voltage cables were replaced. Also, most of the glastic standoffs were doubled in height. The other major problem was running the bipolar 300A p.s.'s at higher currents than they had ever been run before (7 trips). We found that in some of the cases the output FET's were blowing. During the shutdown, following run 6, all of the linear FET's in the output stage had their current sharing aligned. We did not check the FET's that act as switches in the H-bridge. Although this alignment of the linear FET's was a good thing to do it was not the ultimate problem. We still had problems with these supplies running at high currents in run 7 and at this time these p.s.'s are still being evaluated.

More Recent Problems

In runs 4, 5 and 6 there were problems which we tried to address each time and improvements were made. This paper was not meant to cover run 7 however the RHIC ps

problems did increase in run 7. The MTBF_ps_any dropped to about 14 hours. The major problems here were the main power supplies, the bipolar 300A p.s.' and then the bipolar 150A p.s.'s. The unipolar p.s.'s also caused a significant amount of downtime but most of these problems are understood and will be fixed during the summer shutdown after Run 7. Air Conditioning is being added to the buildings to improve reliability. There have been issues with connections that can cause problems that come and go and we seem to be struggling with this a lot. The p.s. problems are all being evaluated. Especially the bipolar 300A and 150A problems which are dominated by error faults, off trips and ac phase faults. The error faults are sometimes difficult to reproduce on the bench.

An infrared camera is being used to help find problems before they cause failures. An instrumentation system is being put together to try and catch the source of intermittent problems. A circuit is being installed to get rid of qpa fan switch failures. QPA fan faults will also become fan warnings. New relays are being installed on the current regulator cards to stop the relay failures we have been having.

Summary

The RHIC p.s.'s in run 6 looked like they had made a very good improvement over previous runs however when we started to run them at higher currents and at higher temperatures we started having more problems. Some problems were addressed and improvements have been made after run 6. Adding Air Conditioning will help but there are other issues with the p.s.'s that still need to be addressed and we are doing this now.

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